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Lightning Control and Measurement

AFCRL will soon undertake a series of Benjamin Franklin-like experiments designed to draw lightning strokes to the ground at will. The experiment will consist of firing a rocket into thunderheads. Attached to the rocket will be a fine steel wire of high tensile strength. It is believed that the main discharge of the lightning stroke will follow this wire to the ground, vaporizing the wire in the process and creating an ionized channel down which subsequent lightning strokes may be channelled. From these experiments, AFCRL hopes to learn more about lightning characteristics --- the radio frequencies generated, the currents and energy of the stroke, and the possibility of coupling energy to the ionized channel created by the vaporized wire. This ionized channel may possibly be used as an antenna for very low frequency transmissions.

The channelling of lightning strokes, however, is only one phase of the overall program concerned with the transmission of very low frequency signals. It is hoped that wires can be carried to altitudes of 30,000 feet or so by means of rockets. An antenna of this length provides a highly efficient antenna for the transmission and detection of VLF energy.

First experiments will be made with small rockets to test techniques for properly unreeling the wire as the rocket is fired. When such techniques are worked out, high altitude shots with larger rockets will be made.

(Propagation Sciences Laboratory, AFCRL)

TO OUR READERS:

With this first edition of the "OAR RESEARCH REVIEW" we are launching an effort which we hope will have something in it for everybody.

Originally the publication which the "REVIEW" has supplanted, the "Weekly Activity Report", was conceived as primarily a scientific publication designed to let scientists know what other scientists were doing. As time went by, however, the "Report" became more popularized, in order to attempt to inform decision makers, who are largely non-scientific, of activities and achievements in basic research.

In the OAR RESEARCH REVIEW we will attempt to satisfy the information needs of both the scientist and the non-scientific decision-maker, since we feel each is of importance. It is inevitable that many decisions concerning basic research, from the budget that supports it to the manner in which it is fed into applied research and development activities, are made by people who are not scientists. We feel that it is imperative that these people be informed about research in progress, and understand something of its potentialities, It is equally imperative that the scientist be kept up-to-date on research projects occuring within his areas of interest.

Those of you among our readers who feel a need for further information about a topic covered in any issue are urged to contact the author or originating laboratory direct. Addresses for use on such occasions are shown on page 12 of this issue.

Constructive criticism and suggestions for improvement will be most welcome, and should be directed to this headquarters, ATTN: RREI.

Daniel E. Hooks

DANIEL E. HOOKS
Major General, USAF
Commander

genie maker

Most of us understand that each of us is a collection of molecules, held together individually and collectively in functionable and sometimes eye-pleasing fashion by chemical forces. That is, we understand this if by "understand" we mean "be familiar with." Most of us have the same understanding about our food, our homes, our conveniences and our weapons. They are all collections of molecules held together as ensembles and as units by chemical forces. But to achieve "true" understanding chemists have sought, in the half-century just past, to learn the natures of the different types of these chemical forces. For instance, take the interatomic sharing of electrons known as the covalent bond. Concerning this the chemist has asked, "What is the role of the quantized motions of the electrons?"

Two landmarks in this quest have been Gilbert Newton Lewis' 1916 paper, "The Atom and the Molecule", and Linus Pauling's 1938 book, "The Nature of the Chemical Bond". Today, another 20-odd years later, the raising of a third landmark appears likely by AFOSR contractor Harrison Shull of Indiana University, whose work has led some scientists to suggest, to his modest embarrassment, that he write a book on "The Real Nature of the Chemical Bond".

Lewis in 1916 climaxed chemists' attempts to show that the chemical bond was a manifestation of electron properties. He laid the foundation of the electron theory of chemical valence, both for the donation of electrons from one atom to another in ionic bonding and for the sharing of an electron pair between two atoms in the covalent bond.

Pauling in his papers and 1938 book brought the picture into clearer focus. In terms of electron properties he explained the reasons for the geometrical relations of an atoms' bonds, for interatomic distances, and for the concept of stabilization of a molecule by resonance among a number of "contributing" structures. (His resonance concept flowered, to the dismay of Soviet ideological chemists.) He showed that a bond can simultaneously have both covalent (electron sharing) and ionic (electron transfer) characters. Intuitively he expressed this relationship fractionally. The O-H bond in water, for example, was described as having 39% character.

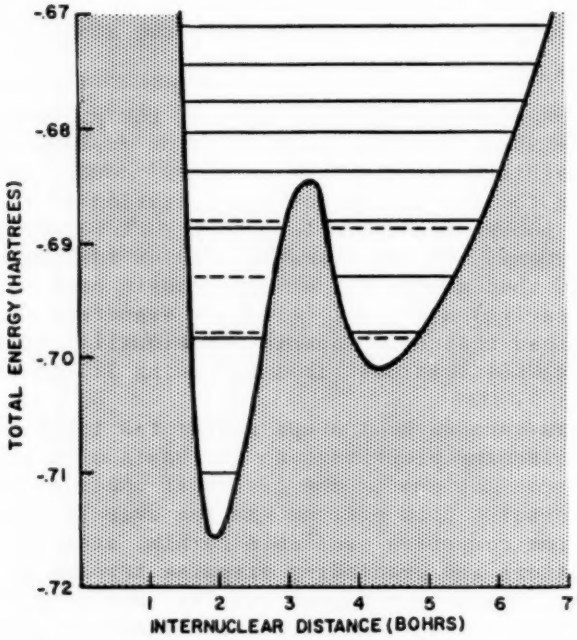
Now Dr. Shull has gone several steps nearer the ideal of fully accounting for all molecular properties on the basis of a priori calculations of electron motions in the fields of their nuclei and of each other. In pursuing this end, he has for over 10 years extracted the utmost from computers available to him, starting with ordinary desk calculators and proceeding stepwise through an IBM 650 augmented with tapes. The computational results have often surpassed others' similar calculations even on bigger and faster equipment.

This is testimony to the cleverness and thoroughness of Dr. Shull's equations and programming.

Among Shull's many new conclusions is that, in contrast to Pauling's approach, the covalent and ionic characters of a bond are independent. He found this as a natural consequence, oddly enough, in the case of bonding two atoms having equal attraction for electrons, the so-called homopolar case. But when he turned to the case in which electrons are attracted more strongly by one of the two atoms than by the other, the heteropolar case, this independence of covalent and ionic characters actually turned out to be necessary.

On another sector of the front, for the first time with modern computers a complete theoretical analysis of the molecular hydrogen spectrum is proceeding toward completion. In the course of this, Dr. Shull and Dr. Ernest Davidson directly computed, from the quantized motions of two electrons in the fields of each other and of two protons, the rotational-vibrational term levels of a first excited state of H_2. They eschewed the common practice of tailoring the theoretical potential energy to an experimental "best-fit" curve. Instead they directly calculated the rotational-vibrational eigen functions of the theoretical curve, whose form had been expected to be the usual energy minimum at a favored internuclear distance. A surprising result happened: the curve contained a double minimum (see figure)!

HYDROGEN MOLECULE
ENERGY OF FIRST EXCITED $^1\Sigma_g^+$ STATE



Dr. Shull believes it likely that mysterious bands in the H_2 spectrum, previously believed to belong to doubly excited states, instead arise from such double minima.

These achievements are monumental, but Dr. Shull has not been content to rest on his orbitals. He turned to a subject on which 20th century chemists have been a frustrated group. Their frustration, like that of the average man, lay in seeing the desired object but not being able to grasp it. The object, since the advent of quantum mechanics, has been to calculate molecular properties, including chemical reactivities, from the products of individual electron wave functions. This is known to be possible, but for molecules more complicated than diatomic it requires, as matters now stand, nearly impossibly long and complicated computations. To ease this situation, Dr. Shull has introduced the notion of geminal (electron-pair) wave functions. He postulated that a proper product function of geminals is adequate for discussion of the principal chemical properties of molecules. Then he showed that such a wave function has both of the properties essential to the bond energy concept: (1) the energy of a molecule is the sum of the energies of its individual bonds and (2) typical bond energies vary little from one molecule to another. These concepts are sufficiently general to include localized bonds, unshared electron pairs, odd electrons, and states of various multiplicities. This is a marvelously broad list compared to past capabilities.

Whether or not Dr. Shull ever does write "The Real Nature of the Chemical Bond", his work will stand as a milestone along with Lewis' and Pauling's on the long road to full chemical understanding. That understanding will ultimately confer upon the chemist a genie's power. This is the power to fashion all materials up to the optima which Nature will allow. Among the genie's beneficiaries will be the people concerned with material strengths, endurances, electrical properties, energy conversions, biological problems, and presently unconceived Air Force requirements.

Refs: "Correlation Energy in the Hydrogen Molecule". AFOSR-340. Ann.Acad.Reg.Sci.Upsal., Mar 1959, 65-74

"Single-Center Wave Function for the Hydrogen Molecule". AFOSR-342. J.Chem.Phys., 30, 1314-1322, (1959).

"Natural Spin Orbital Analysis of Hydrogen Molecule Wave Functions". AFOSR-341. J.Chem.Phys., 30, 1405-1413, (1959).

"On the Comparison of Theoretical Calculations on Diatomic Molecules with Experiment". AFOSR-TN-60-1034. J.Chem.Phys., 33, (1960).

"Electronic Structure of the Ground State of the Lithium Hydride Molecule". AFOSR-TN-1131.

"The First Excited $^1\Sigma^+_g$ State of the Hydrogen Molecule". AFOSR-483.

"First Excited $^1\Sigma^+_g$ State of H_2: A Double Minimum Problem". J.Chem.Phys. 33, 1955 (1960).

"The Chemical Bond in Molecular Quantum Mechanics". AFOSR-494.

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SOLAR PROTON **SHOWER HAZARD**

Fast solar protons may be the biggest hazard the space traveler will have to face. Unlike Van Allen radiation, the position of which is known and presumably can be avoided, solar proton radiation is intermittent and cannot be easily predicted over long periods. To the unprotected man solar protons can be exceedingly dangerous and can damage some types of sensitive instruments.

The least expensive defense against damage is simply to avoid proton showers by limiting operations to safe time intervals when they do not occur. This requires reliable predictions of safe intervals. Since March of last year, AFCRL's Sacramento Peak observatory in Sunspot, N.M. has been studying methods for predicting periods of solar proton showers. During most of this time the Observatory has been making 5-day predictions. Attention is now focused on extending the forecast period.

Dangerous proton showers emanate in solar flares. They arrive at the earth from a half hour to six hours after the peak brightness of the flare. What complicates the prediction process is that not all solar flares produce proton showers. Only about one major flare in four produces such showers. Solar flares, in turn, are closely associated with sunspots and share the same 11-year cycle of activity. At the sunspot maximum, proton flares occur at a rate of about one each month, and prediction is difficult. The last maximum came in 1957-1958. Minimum is expected in 1964 and 1965.

Assuming that space flights are scheduled without regard to solar protons, let us look at what would happen if five space flights each of 5-days duration were made during a year when sunspot activity is at a maximum. We may expect about 13 showers during

this year. The probabilities that the space traveler will enter at least one proton shower is .73. If ten such flights are made, the probabilities rise to .93. On a statistical basis, it would be expected that the space traveler making 10 such 5-day flights would encounter 2.5 showers.

The problem that Dr. John Evans and his group at the AFCRL Sacramento Peak Observatory have set out to solve is the prediction of safe intervals during which no proton showers will occur. The research effort, therefore, is aimed at finding the direct indicators of potential proton showers. There are a number of these indicators. All proton showers so far recorded originate in active centers on the sun. These are regions of sunspot groups, one or two hundred thousand kilometers in diameter. Since only a fraction of the active centers produce large flares and still fewer emit dangerous proton showers, the trick is to spot the dangerous one in advance.

The size and complexity of the sunspot group provides important clues. But in what phase of the development of these groups are protons most likely to be emitted? There is no clear answer. Equipment more sophisticated than an optical telescope is needed to reveal other important characteristics. One such piece of equipment is a differential photometer which will soon be placed in operation at the observatory. This equipment will permit the determination of the differences in brightness of the areas of the sun containing the sunspot groups.

It has been found that a sunspot center with a complicated magnetic field produces on the average about five times as many flares as a center with a simple dipolar or unipolar field. This has led the Observatory to begin the construction of an electronic Zeeman effect magnetometer which will permit the complete mapping of the longitudinal magnetic field of an active center.

Another slowly varying characteristic of active centers which appears to be an indicator is simply the age of the center. About 75 percent of the proton showers come from centers that are between 15 and 30 days old. Less than 10 percent come in the first 15 days.

Other features which AFCRL scientists suspect of being flare indicators are the occurrences of peculiar loop and surge prominences and coronal hot spots. All of the many suspected indices leading to a prediction system must be properly weighted and this involves a rather massive statistical study in order to sort out the significant combinations. Dr. Evans and his group believe, however, that on the basis of the many indicators substantial improvements will be made in predicting techniques.

(AFCRL Sacramento Peak Observatory)

PROGRESS in *Cosmic Ray Physics*

AFOSR sponsored physicists played a major role in the International Conference on Cosmic Rays and the Earth Storm which was held at Kyoto, Japan, from 4-15 September 1961. The conference was arranged in three parts: Part I was on the Earth Storm and was devoted to magnetic storms and their effects, such as ionospheric disturbances; Part II combined the interest of Earth Storm and Cosmic Ray Scientists and was on subjects of mutual interest such as Van Allen zones, solar effects, plasmas and modulation mechanisms; Part III concerned itself with Cosmic Ray phenomena such as composition, spectra, flux and time variations and especially high energy phenomena, i.e., jets, mesons and astrophysics.

Plenary session speakers were chosen from acknowledged experts in a field. The AFOSR has reason to be pleased with the number of people receiving AFOSR support who were selected as plenary session speakers in the cosmic ray part of the program. This was especially to be noted in the plenary session on theory where two of the four speakers, S. F. Singer and E. Parker, are supported by AFOSR and a third speaker, T. Gold, is a member of the AFOSR Physics Advisory Committee. J. A. Simpson spoke at the plenary session on Radiation Belts, Parker and Simpson spoke at the plenary session on Modulation Mechanisms and Gold spoke at the session on Interplanetary Plasmas. M. F. Kaplon was a speaker at the plenary session on Composition, and G. W. Clark and C.B.A. McCusker were speakers at the Extensive Air Showers plenary. The outstanding kudo awarded an AFOSR supported physicist came from Professor Sidney Chapman in his opening speech when, in reviewing the field, he pointed out that Professor Singer had predicted the Van Allen zones a year before they were experimentally detected.

One of the outstanding accomplishments of the Conference was the laying to rest of what has come to be known as "The Li, Be, B controversy". This controversy has centered around the question, 'are any of these elements (lithium, beryllium, boron) in the primary cosmic ray beam or is that which is observed all due to fragmentation'. The Indian, British and American groups - who have been the warring factions - now seem agreed these so called "Lights" are in the primary beam in the ratio of 1:5 of all heavier elements (i.e., atomic number ≥ 6). A number of groups agreed they find heavy primaries up to the highest energies observed. This observation is important to origin considerations. Of equal importance was the report of two separate determinations (the first by an AFOSR contractor, Weekly Activity Report, 5 May 1961) of the $He^3/He^3 + He^4$ ratio at approximately .25. Such ratios can be used to learn about the lifetime of cosmic radiation or the density of matter in space.

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a flexible SOLAR BATTERY

A way has been found to make a solar battery with cadmium sulfide that can be rolled up, like a rug, for convenient carrying in a satellite, and then unrolled to catch the maximum sunlight. It is too early to predict the practical value of such a battery, but it gives promise of delivering more power for a given weight than presently used equipment, and of costing only a fraction as much. The first experimental batteries were produced by the Harshaw Chemical Co., during work on a contract financed by the Flight Accessories Laboratory of the Aeronautical Systems Division, and monitored by Mr. D.C. Reynolds of the Aeronautical Research Laboratory.

The ideas that led to this development grew out of the research program of the Aeronautical Research Laboratory in a manner that typifies what often happens when basic research, from which no practical benefit can be predicted, is undertaken by an agency that is interested in practical benefits. This basic research program, which has been under the leadership of Mr. Reynolds, for the past several years, started with a small effort to grow purer and larger crystals of cadmium sulfide and zinc sulfide, in order to measure their optical properties, and so learn something about their fundamental structure. It has grown into a well rounded program in compound semiconductors that has resulted in over forty scientific publications and papers and has reflected credit on the Air Force in the World scientific community. The present rate of production of new scientific knowledge by this program is high, and other practical benefits may accrue.

When it was decided, in 1952, to build a program of basic research in the Laboratory, recent developments in our knowledge of the solid state indicated to observant physicists that a new frontier of knowledge was due to open up in solid state physics, with developments of major importance to metallurgy, to electronics and to magnetics. Since all of these fields were of key importance in Air Force weapons systems, the solid state was a most promising place to work.

With the limited resources available, it was decided to concentrate primarily on semiconductors, which had already produced the transistor and might hopefully lead to other developments of importance in electronics. At the time, private industry was engaged in intensive research on germanium, and was beginning work on silicon, these two elemental semiconductors being the most promising for transistor, and similar, applications.

The compound semiconductors, which would be much more difficult to work with, were comparatively neglected. However, it was to be expected that much could be learned from them that would not be learned from the elemental semiconductors. Cadmium sulfide, and some of the

related compound semiconductors combining elements from groups II and VI in the periodic table of the elements, seemed most suitable for study. In addition, some of these have a high energy gap between the valence and conduction bands, that would make them suitable for use for electronic applications at elevated temperatures, if they should prove to have the other necessary properties.

During the research, rapid progress was made by concentrating on the one objective of attaining a better understanding of the fundamental properties of the compound semiconductors, without reference to the nature of any probable applications. First, a technique was developed for growing crystals of cadmium sulfide and zinc sulfide that were purer than had been grown previously and large enough for practical studies of their optical properties. This technique has since been used in many other laboratories, in this country and abroad, and crystals have been furnished to domestic and foreign laboratories conducting research in this area. When suitable crystals were available, research was extended from the measurement of optical and electrical properties at ambient and higher temperatures, and atmospheric pressure, to temperatures in the neighborhood of absolute zero and pressures up to a quarter of a million pounds per square inch. Work was done also with cyclotron resonance, electron paramagnetic resonance, the Hall effect, and bombardment with electrons at voltages up to 200,000, which can tear atoms from the crystal lattice.

Among the new scientific discoveries made with respect to cadmium sulfide, were (1) a photovoltaic effect produced by photons of longer wave length, and hence lower energy, than would be expected in view of the large energy band gap mentioned earlier, (2) a possible increase of a million-million-fold in the conductivity of crystals when exposed at low temperatures to light from the blue end of the spectrum, or ultraviolet light, and (3) a shock induced emission of light from the last mentioned crystals that has not been adequately explained.

The first of these discoveries, together with the general properties of cadmium sulfide, led to a contract with the Harshsaw Chemical Company, involving some applied research, designed to make photovoltaic cells, or solar batteries, that would give a higher efficiency than the silicon cells now used, and especially a higher energy output in watts per pound. Since the photovoltaic effect takes place at a thin surface barrier, the work was directed to producing such barriers on thin films of cadmium sulfide, supported on a light-weight substrate. Problems were presented in finding a suitable substrate, in producing a thin layer of highly pure cadmium sulfide on this layer, and in the treatment of this film to produce a rectifying barrier with the proper characteristics: the magnitudes of the optical absorption and the conversion efficiency were unknown, and theoretical problems related to the fundamental structure of the barrier layer and the phenomena involved in the photovoltaic response interposed themselves. A theory which helps to

explain the phenomena involved was developed and is still being checked in the present research program.

During the work it was found to be practical to bend the films, and so to roll up the solar battery. This added a most appealing and valuable feature for space applications.

In the present stage of development the measured efficiency at which these cells convert the energy of sunlight into electrical energy depends on the area of cell being measured. For large areas, it is about 1%. For small areas it is 5%, which may be compared with roughly 10% for the best single crystal silicon cells now used in satellites or 8% for the best single crystal cadmium sulfide cells that have been made in the laboratory. At 1% efficiency, the power-to-weight ratio, in watts per pound, is essentially the same as that of present cells, and preliminary estimates place the cost of manufacture 25% to 75% lower. There is every reason to believe that the film cell can be made only half as heavy as at present. If this is done, and if the efficiency of large areas can be made only 2%, the power to weight ratio will be about four times that of present cells, and the cost will be only a small fraction of the present cost. Under these conditions, the savings from this development alone would cover the entire cost of the research many times.

LEE DEVOL, Chief
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Radar Signature Measurement of Needles Package

AFCRL has completed for Lincoln Laboratory a series of radar cross-section measurements of the West Ford dipole dispenser package. Purpose of the measurements was to find a characteristic radar signature for the complete package, and for the empty canister after the dipoles had been spun off. By means of such a radar signature, it may be possible to determine whether the dipoles did in fact leave the package. The dipole canister has a diameter of about six inches.

(Since the canister was fired on 21 October from Point Arguello, California, no radar returns have been obtained from the dispersed dipoles, although it is almost certain such returns would have been obtained on Lincoln's X-band radars. Lincoln Laboratory, however, first observed on 3 November what is believed to be the canister. The canister was detected using Lincoln's UHF radar on Millstone Hill.)

(Electromagnetic Radiation Laboratory, AFCRL)

on the
VISCOSITY OF DISSOCIATED AIR

Hypersonic flow, especially at high altitude, tends to be dominated by viscous effects, and in order to calculate various features of such flows, including surface heat-transfer rates, surface pressure, etc., it is important to have knowledge of the transport properties of air in its highly-excited state behind a strong shock. Here the gas is at very high temperature and is substantially dissociated.

A number of calculations are available concerning the viscosity of dissociated air. These calculations tend to be quite elaborate, being based on a complete kinetic theory formulation together with more or less uncertain postulates concerning the basic interaction parameters between the particles involved.

In view of the uncertainty of the basic information used, and the rather special requirements for flow calculations, Dr. F. K. Moore of Cornell Aero Lab, working under AFOSR sponsorship, has demonstrated that transport calculations have been made rather too complicated and that the aerodynamicist, at least, may often take a simpler view of the matter than the physical-chemist.

In particular, Dr. Moore found that a simple linear formula (see AFOSR 1554) is a very satisfactory substitute for the complete matrix ordinarily used, at least when the concentration of atoms in the air mixture is moderately small. In the course of evaluating this simple formula, it was found that a previous set of complete calculations (Bauer and Zlotnick) embodies an algebraic error which rather substantially affects their results. In AFOSR 1554, this error was corrected only for a few cases needed for comparative purposes in the present study.

An important physical feature of the linear formula mentioned above is that it requires information about molecule-molecule and molecule-atom collision processes but not about atom-atom collision processes, as long as these are of the order of magnitude commonly supposed. Thus, it appears that for certain practical purposes one is relieved of the necessity to know the atom-atom interactions, which are inherently very complicated owing to the powerful chemical involvement of particle pairs of this type. To turn the argument around, one may say that this result shows how the previous more

elaborate calculations can, so to speak, get away with making rather questionable assumptions concerning this type of interaction because it doesn't matter much anyway.

Another interesting feature of the linear perturbation formula for viscosity coefficient concerns the accuracy requirement for the knowledge of collision characteristics to be used in this or other formulas. It is conceivable as an approximation that one might calculate the viscosity of dissociated air ignoring the fact that some of the particles are atoms, and instead assume that only molecules are present. Such a result may be corrected by using the linear formula described above for the effects of the presence of atoms. Now, it appears that if a certain error is made in defining the atom-molecule collision process, then an error 18 times as large is made in the effect of concentration change on viscosity. Thus, it is concluded that unless the atom-molecule collision is known within a very few per cent, there is no point of elaborating on the very simplest calculation, which assumes that the gas is composed entirely of molecules.

For use in the equations of motion (that is, for calculating heat-transfer rates and the like), another effect of the presence of atoms enters from the state equation used to form the appropriate aerodynamic transport properties. This effect of atom concentration is, at the same time, larger than the affect on viscosity itself, and is also much more firmly established. Thus, for aerodynamics, it is concluded that one may as well calculate the appropriate transport properties as though the only effect of composition change came from application of the state equation. This leads, of course, to very simple formulas.

The present study has certain implications about experimental work undertaken to describe transport properties of dissociated air. First, boundary-layer, or aerodynamic, types of experiments are not likely to produce information about interaction processes, owing to the swamping effect of the state equation. Rather, molecular beam methods must apparently be used. Secondly, direct measurements of viscosity coefficients, for example by use of the molecular beam, would be extremely effective in defining atom-molecular interaction parameters, if the effects of composition on viscosity coefficient could be measured with decent accuracy.

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GPO 924173

Project *Stargazer* set for Spring

Air Force Cambridge Research Laboratories personnel will launch a manned balloon-borne astronomical observatory this spring. This balloon flight, called Project STAR GAZER, is a part of a basic research program in space environments being conducted by the Office of Aerospace Research. The primary purpose is to determine how manned balloon observatories should be designed, built, staffed and operated. Such knowledge will be needed to sustain manned balloon astronomy if unmanned and satellite systems are unable to produce all of the astronomical information scientists need.